

Multilayer record carrier and method of manufacturing thereof and recording thereon

The present invention relates to a multilayer record carrier such as a recordable optical disk of the write-once or rewritable type suitable to be scanned by a single scanning device and provided with at least two substantially parallel information layers, wherein data is written in units of blocks on tracks of the at least two information layers. Furthermore, the present invention relates to a method and a recording apparatus for recording data on such a record carrier, and a method of manufacturing such a record carrier.

Optical data storage systems, such as optical disk drives, allow a storage of large quantities of data on an optical medium. The data is accessed by focussing a laser beam onto the recording layer of the medium and then detecting the reflected light beam. In reversible or rewritable phase-change systems, optical media with two stable phases is used. A data bit is stored on the media by converting a small local area to one stable phase. The data bit can be erased by reverting the written area back to the starting phase. The starting phase is typically a crystalline phase and the laser beam writes data by locally converting the material in the data layer to a stable amorphous phase. This can be achieved by heating the crystalline region above its melting point and then cooling it quickly so that the disordered structure gets fixed in place, resulting in an amorphous structure. The data bit can later be erased by converting the amorphous phase back to the starting crystalline phase. This is done when the amorphous region is heated and maintained at or above its crystallization temperature, or alternatively melted and slowly cooled until the region is crystallized. The data in this type of phase change system is read or detected as a change in reflectivity between a crystalline region and an amorphous region on the optical medium.

To increase the storage capacity of an optical disk, multiple recording layer systems have been proposed. An optical disk having two or more recording layers may be accessed at different spatially separated recording layers by changing the focal position of a lens. The laser beam is transmitted through the nearer recording layer to read and write data on the farther recording layer or layers. Multiple recording layer disks require that the intermediate recording layers between the disk surface onto which the laser light is incident and the last or farthest recording layer from that surface be light-transmissive. To maximize

the disk storage capacity of such optical disks, the recording density is substantially constant across the entire disk surface.

In (rewritable) optical recording with random access, the data is usually written in units of ECC blocks (e.g. in CLV systems without headers), in fixed recording unit blocks of a fixed fraction of an ECC block, such as for example 2 Kbytes or 4 Kbytes of user data (e.g. in Zoned Constant Angular Velocity systems with headers where the distance between two headers is an integer multiple of these recording unit blocks), or in variable length fractions of an ECC block (e.g. in Digital Video Recording systems where the ECC block size is not an integer multiple of the distance between two headers, and writing is "simply" stopped before a header and restarted after a header with the inclusion of some segment run-in and segment run-out data to guarantee proper behavior of the electronics). These fractions of ECC blocks are called "Recording Frames" in DVR systems and "SYNC Frames" in DVD systems. In optical record carriers with headers, the record carrier is subdivided in sectors, each sector comprises a header containing an address uniquely identifying the sector and a recording unit block to which user data, preferably protected by an error detection and correction code (ECC), is recorded.

In DVR systems a Zoned Constant Angular Velocity (ZCAV) system is used. In such systems the capacity of a sector is not constant over the disk. The linear density is approximately constant and the number of tracks per zone is constant, but the length of a track (i.e. one circumference of the disc) is increasing with a factor of 2.4 from inner to outer radius of the disc, while the number of headers per revolution is constant. Thus, the number of bits between two headers is increasing. The DVR system and format is described in T. Narahara et al, "Optical Disc system for Digital Video Recording", Techn. Digest ISOM/ODS (MD1) July 11-15, 1999, Kauai Hawaii, SPIE Vol. 3864 (1999), 50-52 and Jpn. J. Appl. Phys. 39 Pt. 1 No. 2B (2000), 912-919, and in K. Schep et al, "Format description and evaluation of the 22.5 GB DVR disc", Techn. Digest ISOM 2000 (September 2000).

When data is written, the newly written data has to be linked with the data that is already present in a controlled way to guarantee the validity of both the already present data as well as the newly written data. For example, when writing a new block behind an already written block, two measures are taken. First, the new block should not be written over the user data in the already present block. This is guaranteed by introducing a gap between the end of the present data block and the start of the new data block. Second, the new block should be read correctly, i.e. the reading electronics should have the ability to resettle, for example, the amplitude (by a gain control function) and the frequency and the phase (by a

Phase Locked Loop for data detection). This is guaranteed by preceding the new data with a preamble field which contains a repeated pattern long enough for the circuitry to stabilize and be well settled before the first user data is read.

Fig. 6 shows a principle recording pattern of this general method wherein a recording unit block (i.e., a physical cluster) always ends with a postamble (PoA), i.e. a specific pattern to signal the end of user data (a kind of synchronization pattern), a guard field, i.e. a field containing dummy data to overwrite possible present old data which could confuse read-back of the newly written data such as, for example, the PoA of a previous recording, and a gap or gap portion to guarantee that the data of a possible present next cluster is not overwritten. The next recording unit block (i.e., the next physical cluster) starts with a gap, again to prevent overwriting, a guard field G1 and a preamble PrA. The area comprising the postamble PoA, the guard fields G1 and G2, the gaps and the preamble PrA is called the data linking area used for linking succeeding recording unit blocks (i.e., succeeding physical clusters).

The sinusoidal wave form indicated in Fig. 6 indicates a wobble signal recorded on the optical disk and used as a timing reference for deriving the write clock and as a position reference indicating the writing position. Predetermined maximum tolerances $\Delta 1$, $\Delta 2$ and $\Delta 3$ are allowed with respect to the start of the postamble PoA, and the end and start of the guard fields G1 and G2, respectively.

In dual or multilayer systems, the above linking method leads to the problem that the lower layer is read while a significant area of the laser beam passes through the gaps of the upper layer or layers. Thus, the transmission characteristic or the degree of transmittivity of the upper layer differs in dependence of the gaps since the transmittivity of the upper layer is different in the written and in the non-written state. This problem increases when the gaps are large such as, for example, in DVR systems where the gaps may have a length of typically about $150\text{ }\mu\text{m}$ while the diameter of the beam in the upper layer is about $40\text{ }\mu\text{m}$ when reading the lower layer and when the gaps are at the same angular position in neighboring tracks such as, for example, on the radial areas of a CLV or ZCAV system where an integer number of ECC blocks fits almost exactly on an integer multiple of one or several circumferences.

Furthermore, in dual or multilayer phase change disks, the effective power in the deepest (second) layer differs according to the physical structure of the upper (first) layer. For example, the transmission characteristics or the transmittivity of the header area and of the rewritable land/groove area of a phase change disk are different. The effect of the header

area in the upper layer on the deepest layer is the sum of two effects. First, the headers have a transmission characteristic which may differ from that of the land/groove area. When no data is recorded in the land/groove area this difference is in general relatively small. However, when data is recorded in the land/groove area the difference may be substantial. Secondly, just before and just after the header area the groove is not yet written with phase change data due to the fact that in a DVR system the segment run-in starts and the segment run-out ends with a gap before the data is actually written. This gap is used for, for example, the random start position shift (in the segment run-in) used for increasing the number of overwrite cycles in a phase change disk and as reserved space (in the segment run-out) when, for example, the bit length used is slightly longer than the nominal length due to inaccuracies when deriving the write clock from the wobble signal or when writing with a (non-locked) crystal clock. Moreover, after and before these gaps, a guard field and a preamble field PrA is written e.g. to allow settlement of the electronics.

Thus, the transmission problem due to the gap portion in the upper layer occurs between data clusters and between a data cluster and a header area.

The transmission problem due to the header area is significantly increased in case of a (random) misalignment between the header spokes of the upper and of the lower information layers. Header alignment or correspondence requires a tight centering and angular alignment between the two layers. E.g., in the DVR system less than approximately one wobble, i.e. less than 30 μm peak-to-peak, would be a preferred range for the displacement between the headers in the two information or recording layers. This displacement may result from unroundness (assumed to be small, i.e. less than a few μm), eccentricity (decentering of the center of the spiral track with respect to the central hole) and angular difference. The decentering of the spiral track with respect to the central hole is introduced mainly in the moulding step of the disk mastering and replication process. The above mentioned preferred allowed displacement range between the header corresponds to an allowed eccentricity of 15 μm peak-to-peak and an allowed angular misalignment of 0,015 degree.

Document US 5,715,225 discloses a multilayer optical record carrier and data storage device, wherein two separate optical heads are used to improve the alignment between the different information layers. Each optical head includes its own actuator. By using two separate actuators mechanically and electronically linked, tracking and sector information can be obtained from the appropriate recording layer of the optical storage device which was preformed or formatted. Thus, one of the optical heads is continuously

focussed on a recording layer which contains tracking and format information. This recording layer is not necessarily the recording layer on which user data is being recorded or read.

Furthermore, document US 5,764,620 discloses a multilayer optical recording carrier in which the recording layers have sensitivity peaks in different wavelength, while allowing lights having the other wavelength to transmit there through. Each track on the recording layers is divided into a plurality of sectors each of which has an identification section. The identification sections are shifted against one another in the tracking direction to thereby prevent the light beam from illuminating neighboring identification sections simultaneously. As a result, cross-talk or influences between neighboring identification sections can be reduced.

It is an object of the present invention to provide a multilayer record carrier, a method and apparatus for recording on such a multilayer record carrier, and a method of manufacturing such a multiple layer record carrier, by means of which transmission differences in the upper information or recording layers can be reduced without significantly increasing the complexity of the system.

This object is achieved by a multilayer record carrier as defined in claim 1, a recording method as defined in claim 11, and a recording apparatus as defined in claim 18. Accordingly, by setting the length of the first and second guard fields such that the end position of the second guard field of a preceding data block is located within the area of the first guard field of the succeeding data block, the gap portion between neighboring data clusters or data blocks is prevented. Thereby, a uniform transmittivity can be achieved in the upper layers, since no gaps are provided in the linking areas.

Furthermore, the above object is achieved by a multilayer record carrier as defined in claim 6, a recording method as defined in claim 14, and a recording apparatus as defined in claim 20. Accordingly, the length of the first and the second guard fields is set to be greater or equal than half the diameter of a reading beam in the upper information layer when focussed on the lowest layer plus an allowed misalignment between the two layers. Thereby, it can be assured that the length of the guard fields in the upper information layer is sufficient to provide an area with a uniform transmission characteristic or nature through which the beam passes in the upper layer within the beam diameter when focussing on the deepest layer. The whole area covered by the diameter of the reading beam in the upper layer thus comprises written data and no header or unwritten area.

The uniform transmission characteristic can be achieved by writing dummy data into the first and second guard fields.

Preferably, the length of a gap portion provided between the second guard field and the header area or between the header area and the first guard field is greater or equal than the predetermined minimum length of the first and second guard fields. In particular, the length of the gap portions may be equal to the length of the first and second guard fields. Thereby, the length of the gap in the upper layer is chosen such that the phase change data in the upper layer is not "seen" anymore by the reading beam when reading the header area in the deepest layer. By using in the at least two information layers the same length for the gap and guard fields, symmetry between the information layers can be achieved. Additionally, the above object is achieved by a method of manufacturing a multilayer record carrier as defined in claim 22.

The optical alignment of the two information layers assures that the headers of the two layers are provided exactly on top of each other, such that the headers in the upper layer have no effect on the recording performance in the lower layer, since they are always facing another header. By the above proposed increase in the length of the guard field, it can be assured that the beam passes through a uniform, i.e. completely written, area when recording or reading the data in the deepest layer.

The optical measurement and alignment can be performed by using a camera device, such as a CCD (Charge Coupled Device) camera.

Preferably, the alignment marks may be header areas, e.g. header spokes, provided on the at least two information layers. In this case, the measuring points may comprise two points located on an inner diameter and an outer diameter of one spoke or at an outer diameter of two opposite spokes, and one point located on a spoke arranged at an angle of 90 degree with respect to said one spoke or said two opposite spokes, respectively. Thereby, two spokes of headers positioned perpendicular to each other can be aligned, such that the alignment is fully determined. In this way, two layers can be fully aligned in one step.

The present invention will now be described in greater detail on the basis of a preferred embodiment with reference to the accompanying drawing figures, in which:

Fig. 1 shows a schematic diagram of a dual layer record carrier and a scanning device for an optical disk player according to the preferred embodiment of the present invention,

Fig. 2 shows a recording structure of an upper and lower recording layer according to the preferred embodiment,

Fig. 3 shows a diagram indicating the relationship between the spacing between two recording layers and the diameter of a reading beam in the upper layer when focussed on the lower layer,

Fig. 4 shows different types of misalignments between two recording layers,

Fig. 5 shows different measurement positions for an alignment procedure and an aligned disk according to the preferred embodiment of the present invention,

Fig. 6 shows a recording scheme with a data-linking area according to the prior art, and

Fig. 7 shows recording schemes with data-linking areas according to the prior art and according to the preferred embodiment of the present invention.

The preferred embodiment will now be described on the basis of an optical disk player for recording on and reproducing from a dual layer optical disk.

Fig. 1 shows a cross-section of the dual layer record carrier 1 and a scanning head of a scanning device 10 for optically scanning the information stored in the record carrier 1. The record carrier 1 has a transparent substrate 5 provided with a first information layer 6 and a second information layer 8 substantially parallel thereto, separated by a transparent spacer layer 7. Although only two information layers are shown in this embodiment of the record carrier 1, the number of information layers may be more than two.

The scanning device 10 comprises a radiation source 11, for example a diode laser which generates a radiation beam 12, such as a laser beam. The radiation beam is formed to a focussing spot 15 via a beam splitter 13, for example a semitransparent plate, and a lens system 14, for example an objective lens. The focussing spot can be placed on any desired information layer by moving the objective lens 14 along its optical axis, as is denoted by the arrow 16. Since the first information layer 6 is partially transmissive, the radiation beam can be focussed through its layer on the second information layer 8. By rotating the record carrier 1 about its center and by displacing the focussing spot in a direction perpendicular to the tracks in the plain of the information layer, the entire information area of an information layer can be scanned by the focussing spot. The radiation reflected by an information layer is modulated by the stored information into, for example, an intensity or direction of polarization. The reflected radiation is guided by the objective lens 14 and the beam splitter 13 towards a detection system 17 which converts the incident radiation into one

or more electric signals. One of the signals, the information signal, has a modulation which is related to the modulation of the reflected radiation, so that this signal represents the information which has been read. Other electric signals indicate the position of the focussing spot 15 with respect to the track to be read. The latter signals are applied to a servo system 18 which controls the position of the objective lens 14 and hence the position of the focussing spot 15 in the plain of the information layers and perpendicular thereto in such a way that the focussing spot follows the desired track in the plain of an information layer to be scanned.

Furthermore, the scanning device comprises means for causing the focussing spot to follow a track, for example in the form of the above mentioned servo systems, and to displace the focussing spot from one to the other information layer. The last mentioned displacement of the focussing spot can be realized by means of the servo system which retains the focussing spot on an information layer. The servo system 18 is controlled by a control unit 36 which operates in accordance with a control program to ensure correct reading of the recording tracks of the information layers 6, 8. The control program may also be used for writing and erasing information in the record carrier. Furthermore, a write clock may be derived from a wobble PLL clock generated on the basis of a pre-recorded wobble signal, and a write position may be derived from a wobble counter (not shown). The wobble PLL clock or frequency may further be used to control the disk rotation speed during writing.

It is noted that the invention is also applicable for other disk structures, e.g. the DVR structure where the substrate serves as a rigid carrier (carrying embossed information), while readout is performed through a thin (100 μm) cover layer. Furthermore, a two-lens or dual-lens objective (e.g. as in the DVR system) may be used instead of the single objective lens 14 shown in Fig. 1.

According to the preferred embodiment, the power in the focussed spot 15 in the deepest layer, i.e. the lower information layer 6, is kept at its optimal value by providing the following measures. {Guard fields with dummy data are provided in the segment run-in and run-out area, with a length to prevent the recording in the deepest layer to be effected by the empty-written transmission area in the upper layer} The length of the guard fields may be greater or equal than a predetermined minimum length which corresponds to the sum of half the size of the beam in the upper information layer 8 when focussed on the deepest or lower information layer 6 and the allowed misalignment. As an alternative, the length of the guard fields between successive data units which are not separated by a header area can be selected in such a manner that the guard fields overlap and a gap is prevented. Furthermore, the headers of the two or more information layers in the (re)writable optical disk can be aligned

within a distance corresponding to the size of the beam in the upper layer when focussed on the deepest layer. This may be achieved by an optical alignment procedure during disk manufacturing.

Fig. 2 shows a recording scheme of the lower information layer 6 and the upper information layer 8, according to e.g. the DVR format, comprising rewritable user data areas, a run-out guard field, a run-out gap, a header area, a run-in gap and a run-in guard. It is noted that in Fig. 2 the preamble PrA and the postamble PoA are not indicated for reasons of simplicity. As can be gathered from Fig. 2, a minimum allowed misalignment is defined between the header areas of the upper information layer 8 and the lower information layer 6.

Furthermore, a beam shape of a reading or writing beam is indicated in the left portion of the diagram, wherein the arrow above the upper information layer 8 indicates the scanning direction. The length of the run-out guard field and the run-in guard field is set or selected so that the area through which the beam passes in the upper information layer 8 is of a uniform nature (i.e. all written data, no header and no unwritten data) within the beam diameter when focussing on the deepest or lower information layer 6. Preferably, the length of the run-out gap and the run-in gap in the upper information layer 8 is chosen such that the phase change data in the upper information layer 8 is not "seen" anymore by the read-out beam when reading the header in the second information layer 6. However, this requirement regarding the length of the gaps is not a strict requirement, since the header area is designed very robustly, and the header detection is not expected to deteriorate much when the signal level (light intensity) is slowly varying.

For symmetry purposes between the two layers, it may be preferred to use the same length for the gaps and guard fields in both layers, although the gaps and guard fields in the lower information layer 6 have no particular protective role related to the dual layer recording system.

The above requirement regarding the length of the gaps and guard fields, leads to a predetermined minimum length of the guard fields (and gaps if full protection of the header area is implemented) of approximately the sum of half the diameter of the beam in the upper information layer 8 when focussed on the lower information layer 6 and of the maximum allowed misalignment between the two layers.

Fig. 3 shows a schematic diagram based on which the relationship between the layer spacing S (between the lower layer 6 and the upper layer 8) and the beam diameter D in the upper information layer 8 can be derived. Based on Fig. 3, the relationship can be expressed as follows:

$$D = 2 \cdot S \cdot \tan(a \sin (NA/n))$$

wherein D denotes the diameter of the beam in the upper information layer 8, NA denotes the numerical aperture ($NA = n \cdot \sin \alpha$, wherein α denotes half of the angular aperture or collection angle of the scanning beam), S denotes the spacing or distance between the upper information layer 8 and the lower information layer 6, and n denotes the refractive index of the layer material. Assuming a distance $S = 30 \mu\text{m}$, a half collection angle $\alpha = 32-34,5^\circ$, and a refractive index $n = 1,5-1,6$, a beam diameter in the upper information layer 8 of $D = 38-41 \mu\text{m}$ is obtained. By adding the allowed misalignment of e.g. $30 \mu\text{m}$, a total minimum length of the guard field of $68-71 \mu\text{m}$ is obtained.

The above-mentioned relatively tight requirement of alignment of the header areas can be achieved by the following optical alignment operation during the manufacturing of the optical record carrier.

Fig. 4 shows different kinds of misalignments and their impact on the spokes of the header areas between the recording sectors of the upper and lower information layer 8, 6. In the pattern on the left side of Fig. 4, a decentering of the center of the spiral recording track with respect to the central hole of the optical disk in the horizontal direction is shown. The same misalignment may occur in the vertical direction of Fig. 4. In the pattern shown in the middle of Fig. 4, an angular misalignment is shown, where the angles of the header spokes of the upper and lower information layers 8, 6 differ. A combination of the above two misalignment types is shown in the pattern on the right side of Fig. 4.

An alignment within the small required tolerance is possible when an optical alignment is performed between the two information layers. By using an optical camera device such as a CCD camera, accuracies down to $10 \mu\text{m}$ or better can be achieved. Preferably, an alignment can be performed where two spokes of headers positioned perpendicular to each other, i.e. at 0 and 90° relative angle, are aligned. This can be achieved by measuring and alignment at three measuring points, as shown in Fig. 5. According to the left pattern in Fig. 5, measuring points M1 and M2 are located at an inner diameter and an outer diameter along one header spoke, and one measuring point M3 is located at another spoke arranged under, substantially, 90° relative angle to the one header spoke. Alternatively, as shown in the middle pattern of Fig. 5, two measuring points M4 and M6 may be located at respective outer diameters of two opposite header spokes, and one additional third measuring point M5 may be located at a third spoke arranged under, substantially, 90° relative angle to the other two spokes. By the above two alternative locations of the measuring points, the

alignment is fully determined. In this way, the two information layers can be fully aligned in one alignment step with respect to both decentering as well as angular misalignment. Effectively, this method relaxes the two tight requirements for centering and angular alignment into one more relaxed requirement on the sum of the two requirements.

5 The pattern on the right side in Fig. 5 shows an aligned disk, where the header spokes of the lower information layer 6 and the upper information layer 8 are arranged at a displacement of less than 30 μm .

It is noted, that the above optical alignment procedure during the manufacturing of the optical record carrier is not restricted to align corresponding segments or header spokes or areas above each other. The alignment operation may as well be achieved
10 by using any microscopically visible or a mechanical alignment mark in e.g. the inner area of the disk or at its outer edge. Then, the alignment may as well be performed by using a camera device detecting the alignment mark, similar to the above procedure.

In the following, a measure for providing a uniform transmission characteristic
15 for the recording pattern shown in Fig. 6 is described. As already mentioned, the gaps between the data clusters or data units lead to a variation in the transmission characteristic of the upper information layer 8.

Fig. 7 shows two recording schemes, wherein the upper one corresponds to the recording scheme shown in Fig. 6, and the lower one corresponds to a recording scheme according to the preferred embodiment, wherein the length of the guard portions G1 and G2
20 is selected to overlap or at least connect to each other, to thereby prevent a gap portion in between.

In particular, the time for supplying the dummy data of the guard fields G1 and G2 to the scanning device 10 is increased in such a manner that the length of the guard
25 fields G1 and G2 are increased such that one guard field extends into the next or succeeding guard field, i.e. the guard field at the end of a block succeeds into the guard field at the start of the succeeding block. Thus, the guard fields G1 and G2 have such a length that their end/start position is in the next/previous guard field. Preferably, those parts or portions of the guard fields G1 and G2 which are never effected by the overlap should have a length
30 sufficient to overwrite possible old data at that position, and sufficient for the electronics to resettle. However, in case a preamble PrA is provided, the length of this preamble PrA may already be sufficient enough. The start position of the guard field G1 at the start of a physical recording or data cluster may be varied on purpose, to increase cyclability, i.e. the maximum

number of direct-overwrite cycles, with typically +/- 64 to +/-1024 channel bits, depending on the format used, e.g. in DVR a variation of +/- 128 channel bits is allowed.

Thus, the above described aspects introduced into the preferred embodiment of the present invention alone or in combination lead to a more uniform effective reading or writing power in the lowest information layer 6. Thus, the power in the focussed spot 15 can be maintained at its optimal value.

It is noted that the present invention is not restricted to the preferred embodiment described above, but can be used in any recording apparatus for recording on a record carrier, where at least two substantially parallel information layers are provided, e.g. magnetic or electric recording layers, wherein the recording data recorded on one information layer influence the reading or writing of the other information layer. The preferred embodiment may thus vary within the scope of the attached claims.

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